PERFORMANCE OF THE ABSORPTION PROCESS IN A SEASONAL SORPTION HEAT STORAGE PROTOTYPE

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ABSTRACT

Seasonal heat storage has great potential to enable renewable heating and seasonal load shifting. Nevertheless, it remains an on going challenge today. The benefits of sorption heat storage are fonud in the potentially lossless storage, when not including charging and discharging processes, and the prospective of greater volumetric energy densities compared to water. In sorption heat storage not sensible heat is stored, but the potential to regain heat. In the framework of the EU funded project COMTES a closed sorption heat storage demonstrator based on sodium hydroxide as sorbent and water as sorbate was developed and built.

The built demonstrator operates on a hybrid basis. Heat is stored in sensible hot water tanks for diurnal storage and in the sorption heat storage system for seasonal storage. This grants the possibility to utilise the benefits of both systems, namely low charging and discharging losses in sensible storage and low heat losses during storage time in sorption storage. The complete system is built into a 7 m long shipping container. A solar collector field with an active area of 18 m^2 mounted on the container serves to cover the total heat demand.

The central component of the sorption system is the interconnected absorber and desorber (AD) and evaporator and condenser (EC) unit. Both units are built as tube bundle falling film heat and mass exchangers similar to a solar thermal chiller. In initial operation with water, 6 kW of water vapour equivalent could be transported from desorber to condenser with a temperature difference between desorber and condenser of approximately 30 K. Nevertheless, absorption tests with sodium hydroxide at a concentration of 50 wt% showed much lower power output below 1 kW. It was found that even though absorption occurred, the process of water vapour absorption is slower than expected. The sodium hydroxide flows over the tube bundle with little water gained, thus releasing little heat. Results from this work and further testing of the speed of absorption have shown that novel heat and mass exchangers are required for sorption heat storage applications.

Keywords: Seasonal heat storage, sorption heat storage, absorption, heat and mass exchanger.

INTRODUCTION

In the framework of the EU funded project COMTES a closed sorption heat storage demonstrator based on sodium hydroxide (NaOH) as sorbent and water as sorbate, has been developed [1,4]. The system operates on a hybrid basis [2]. Heat is stored in sensible hot water tanks for diurnal storage and in the sorption system for seasonal storage. It is expected that the benefits of both systems can be utilised, namely low charging and discharging losses in diurnal storage and low heat losses during storage time in seasonal storage.

The complete system has been built into and onto a 7 m long shipping container [6]. Figure 1 shows the demonstrator system from the outside on the left and from the inside on the right.

Figure 1: Left: Picture of the complete system from the outside. Solar collectors with an active area of 18 m^2 are mounted on top and on the side of the shipping container. Right: Picture of the complete system from the inside. On the left is the heat and mass exchanger assembly, with the sorbent and sorbate tanks in the back, and on the right are solar pump station, fresh hot water station and floor heating pump, in the back the sensible hot water tanks are placed.

In a preliminary work, plate type heat and mass exchangers were constructed. These consisted of double floored plate shaped containments, whereby sorbent was introduced onto the plate, and a heat transport fluid passed through the plates double floored construction. In the present demonstrator, in order to reach a more continuous process, it was decided to introduce the falling film tube bundle concept, which is common in solar thermal chillers. To this accord two heat and mass exchanges were designed and constructed for the absorption and desorption as well as evaporation and condensation process respectively. Both consist of a horizontal alignment of tubes containing the heat transfer fluid and wetted by sorbent (AD unit) or sorbate (EC unit) from a horizontal liquid falling film [3]. Figure 2 shows the heat and mass exchanger design as built in the demonstrator.

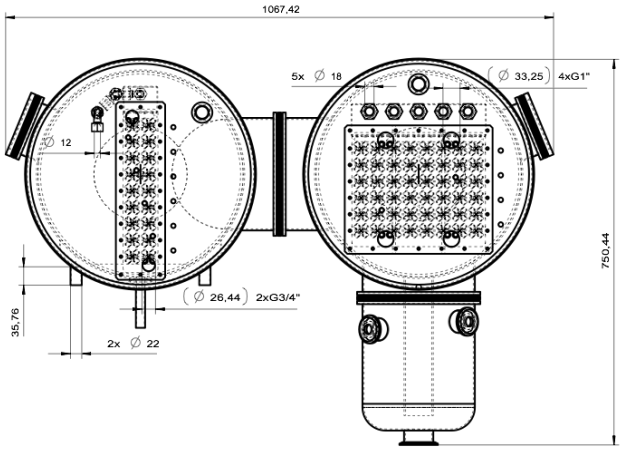

Figure 2: CAD drawing of the heat and mass exchanger, measurements in mm. On the left is the AD unit and on the right the EC unit.

RESULTS

Several absorption tests have been done with the heat and mass exchanger illustrated in Figure 2. Results of two tests are visualised in Figure 3. These illustrations show steady state average values. The blue circles indicate the tube bundle arrays for both the AD and EC units. The heat transport medium flows upward from one tube to the other, as shown by the blue arrows through the circles. The orange arrow shows the flow of the sorbent in the AD unit, this is in counter flow to the heat transport fluid. In the EC unit the sorbate flow is indicated in dark blue. Temperatures are measured inside as well as outside of the tubes at varying levels, as indicated. Volume flows of the sorbent and the heat transport fluids in both AD and EC units are indicated as well as the power input and output.

In operation it was discovered that non condensing gases have a substantial effect on the absorption process. In the figure on the left, operating at a pressure of 1.88 mbar abs. above the water vapour pressure (18.69 mbar abs.) at the given evaporator temperature stable vapour transport equivalent to 1 kW of thermal energy could be reached. On the other hand on the right, at similar settings, the measured pressure was 10.3 mbar above the water vapour pressure (17.4 mbar abs.). In this test no vapour transport was possible.

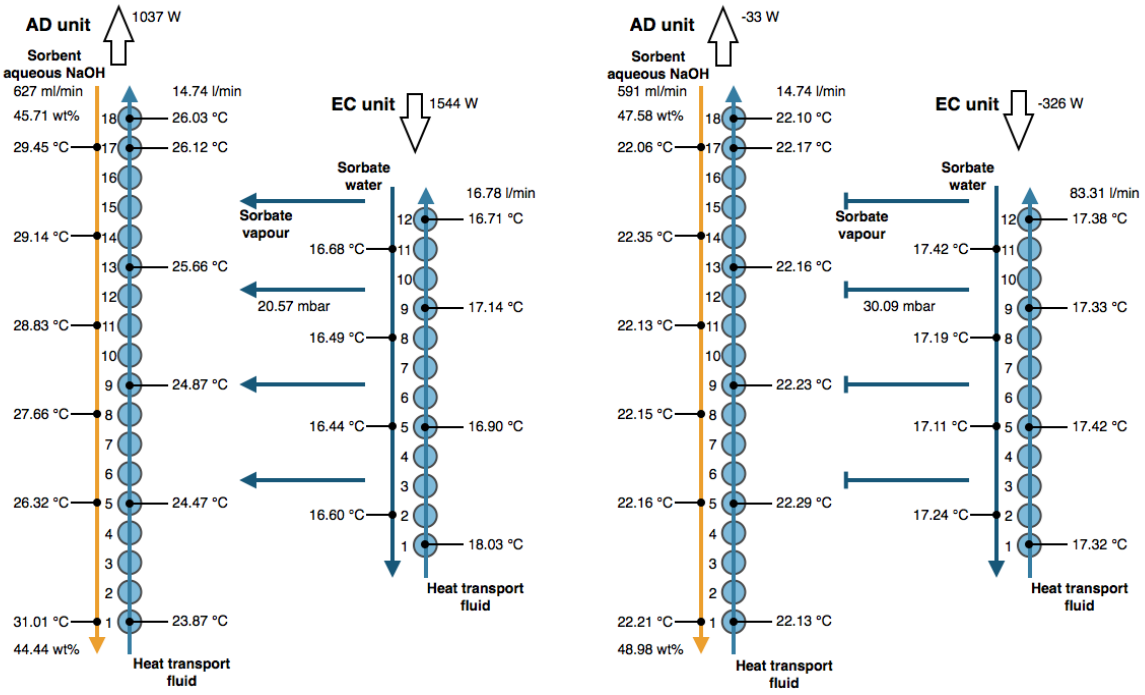

Figure 3: Illustration of the absorber / desorber (AD) and evaporator / condenser (EC) heat and mass exchanger test results. On the left is the result with nearly all non condensing gases removed, on the right a result with approximately 10 mbar pressure resulting from non condensing gases.

Even through an achieved continuous power output of approximately 1 kW, the actual temperature gain was only 2.16 °C, from 23.87 °C to 26.03 °C. Theoretically an output temperature of approximately 56 °C should be possible [5], when neglecting temperature losses. The sorbent concentration reaches only a slight reduction, which explains the low temperature gain and power output.

DISCUSSION

It appears that the conventional heat and mass exchangers as designed in this system and often used in absorption chillers [3] are not fitting the heat storage application. This can be explained as follows: Even though the process of absorption and desorption in the heat storage application is comparable to the solar chilling process, the actual operation differs strongly. Solar chilling follows a continuous full cycle process, sorbent is charged by removing sorbate followed immediately by discharging through absorbing sorbate. Sorbate is condensed and evaporated in a continuous process whereby heat is released or gained from the ambient respectively. In gaining heat from the ambient, chilling is achieved. In this process the quantity of sorbate transported between desorption and absorption is not of primary importance. In the heat storage approach on the other hand a continuous but not full cycle process is at work. This is due to the nature of its role as storage. In its operation, especially in the absorption process, it is of significant importance that a low concentration of sorbent, in other words high sorbate absorption is reached. This has direct impact on the storage energy density. Due to the dependence of the output temperature on the sorbent concentration, absorption must occur in one step and recirculation is not possible. Consequently the exposure time of the sorbent to the sorbate vapour must be sufficient to reach high sorbate uptake. In the described setup about 2 seconds are given.

A further issue is found in the formation of sorbent droplets. Figure 4 shows the AD tube bundle with the manifold evenly supplying small droplets on the first tube. Nevertheless they quickly group to form larger droplets, thus reducing the wetted area of the tube bundle and increasing the fall through time, whereby reducing both contact area and contact time of sorbent to sorbate.

Figure 4: Picture of the tube bundle in the AD unit, showing the flow of sorbent (aqueous NaOH) over the tubes. Fine droplets group, reducing the wetted surface on the tubes.

CONCLUSION

It is found that a novel heat and mass exchanger design for the absorption process in sorption heat storage is required. A possibility could be a heat and mass exchanger consisting of two separate zones. An initial area of only mass absorption, allowing preheating of the sorbent, followed by an area of mass absorption and heat release for heat transport. In the design it is critical that the sorbent is allowed adequate time for sorbate absorption, this could require a sorbent suspension in sorbate vapor time of more then one hour.

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